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[54] **ADMINISTRATION OF A 27-HYDROXYCHOLESTEROL OR PRODRUG THEREOF AS AN ANTI-CANCER AGENT**

[76] **Inventor:** **Norman B. Javitt**, c/o Dept. of Medicine, New York University Medical Cntr. 550 First Ave., New York, N.Y. 10016

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Related U.S. Application Data

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[52] **U.S. Cl.** **514/177; 514/178**

[58] **Field of Search** **514/177, 178**

[56] **References Cited**

U.S. PATENT DOCUMENTS

5,587,368 12/1996 Javitt 514/177

OTHER PUBLICATIONS

Steroids, vol. 53, Nos. 3-5, issued 30 Mar. 1989, Parish et al., "Studies of the Oxysterol Inhibition of Tumor Cell Growth", pp. 579-596, Mar. 1989.

Ji, et al., *Tetrahedron*, vol. 46, pp. 487-502 (1990).

Primary Examiner—James H. Reamer

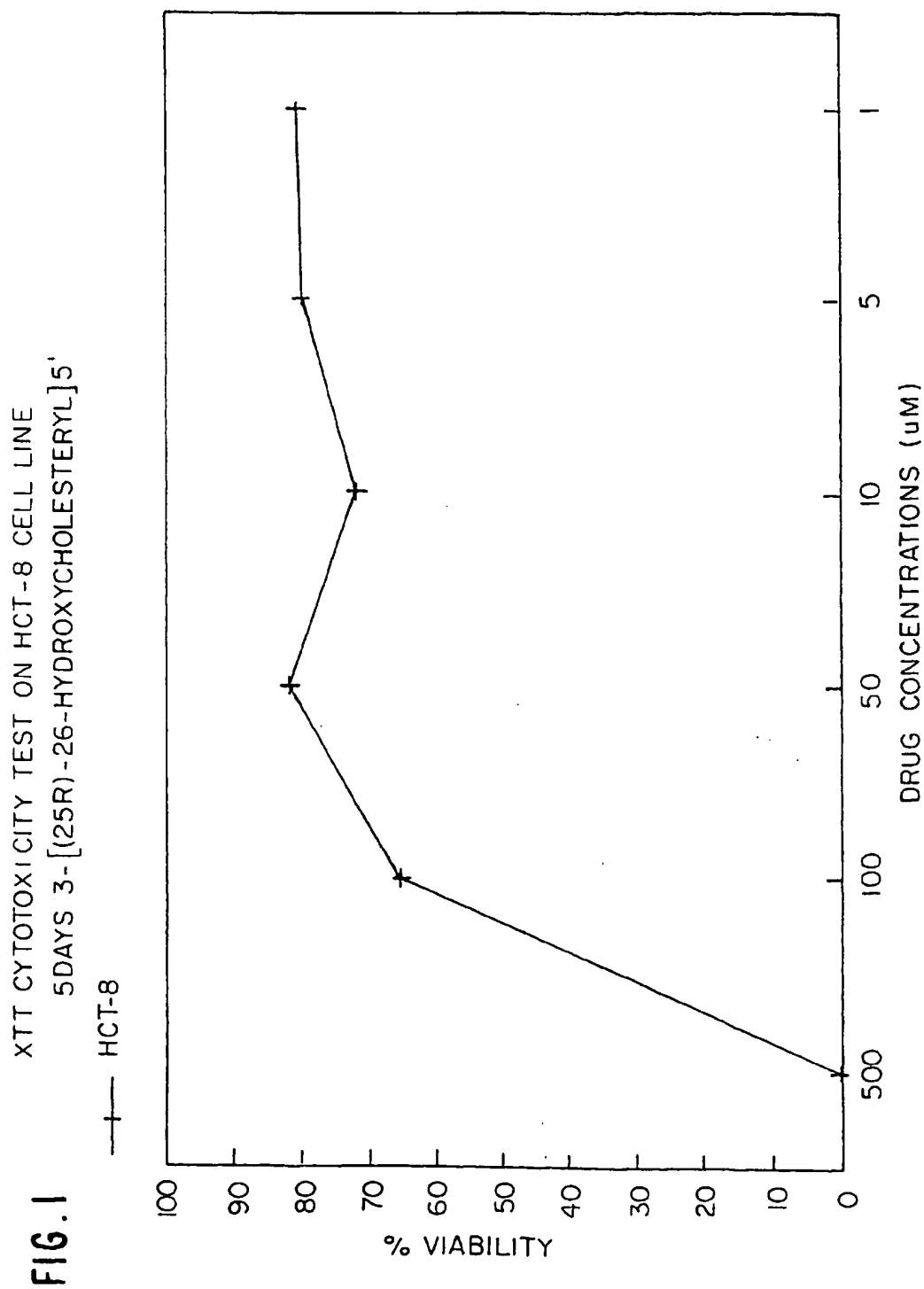
Assistant Examiner—Dwayne C. Jones

Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak & Seas, PLLC

[57] **ABSTRACT**

A method for preventing or reducing restenosis wherein a 27-hydroxycholesterol or a 25,26 and/or 27-aminocholesterol, or a sterol 27-hydroxylase stimulant, is administered in a restenosis preventing and/or reducing amount. The invention also includes a method for treating cancer using 27-hydroxycholesterol.

8 Claims, 1 Drawing Sheet



SUBSTITUTE SHEET (RULE 26)

ADMINISTRATION OF A 27-HYDROXYCHOLESTEROL OR PRODRUG THEREOF AS AN ANTI-CANCER AGENT

This application is a 371 of PCT/US95/12270, filed on Oct. 5, 1995.

The subject application is a Continuation-In-Part of application Ser. No. 08/319,225, filed on Oct. 6, 1994 now U.S. Pat. No. 5,587,368.

BACKGROUND OF THE INVENTION

1. Technical Field

The subject invention relates to methods of using 27-hydroxycholesterol, sterol-27-hydroxylase, and related compounds in the prevention of restenosis. The subject invention also relates to methods of using 27-hydroxycholesterol in the treatment of cancer.

2. Background Information

Various surgical bypass and angiographic procedures are routinely employed for increasing blood flow to an organ, usually the heart. These operative and non-operative procedures injure, to a greater or lesser extent, the interior wall of the lumen of the blood vessel at the target site. This endothelial injury often leads through a cascade of events to restenosis. For example, balloon, laser or rotameter angioplasty, in which a catheter is inserted into the arterial system to place a balloon, laser or blade at the stenosis, is quite successful in widening a narrowed area of a blood vessel lumen. However, endothelial injury occurs at the site of the lesion, leading to restenosis in an estimated 20-40% of patients.

It has been shown in animals that endothelial injury initiates a process that leads to narrowing of the injured artery (stenosis), and this model is related and is used to study the events that occur following endothelial injury.

The major current theory for explaining restenosis is that once the endothelial cells are injured or removed by the invasive procedure, circulating platelets cover the denuded areas and release potent growth factors, such as platelet derived growth factor, which stimulate the growth and migration of underlying smooth muscle cells. Other growth factors, such as fibroblast growth factors, have also been implicated. For these reasons, anti-growth factors are being evaluated for the prevention of atherosclerosis.

Many factors are thought to potentially participate in restenosis. Further, hemodynamic forces responsible for the original lesion are not generally alleviated by angioplasty and may be aggravated at plaque disruption. The thromboresistant nature of the arterial lumen is reduced due to the generation of markedly thrombogenic surfaces of complex geometrical configuration, and changed permeability characteristics permitting possible direct interaction between blood-borne elements such as the aforementioned platelets and the arterial lumen. In summary, the surgical and angiographic procedures necessarily result in injury to vessel walls, which results in restenosis in 20-40% of patients.

27-hydroxycholesterol (cholest-5-ene-3 β , 27-diol) is normally present in biological fluid after neonatal life. Recently, the IUB changed certain rules of nomenclature, and the compound now referred to as 27-hydroxycholesterol was previously called 26-hydroxy-cholesterol. Two methyl groups are attached to carbon number 25 of cholesterol, but only one can be enzymatically hydroxylated, which was previously named carbon number 26, but is now named as carbon number 27.

U.S. Pat. No. 4,427,688 by Javitt describes the administration of 26-hydroxycholesterol (sic., 27-hydroxycholesterol) and various derivatives and analogs thereof for reducing cholesterol synthesis and/or cholesterol accumulation in the body tissues; hence, teaching the use of 27-hydroxycholesterol compounds for the treatment of atherosclerosis. Thereafter, as disclosed in U.S. Pat. No. 4,939, 134, Javitt, et al. discovered that 27-aminocholesterol, and certain amino-substituted analogs and derivatives thereof, are more potent inhibitors of cholesterol synthesis and accumulation than 27-hydroxycholesterol.

Javitt filed Japanese Application 107488/82 in 1982, published as 019206/91 on Nov. 14, 1991 ("JPA"), largely corresponding in disclosure to U.S. Pat. No. 4,427,688 with insertion of additional information for further supporting use of 27-hydroxycholesterol in treatment of atherosclerosis. The JPA notes that Kandutsch, et al., *Science*, 201, 498 (1978) mentioned that oxygenated cholesterol has an inhibitory effect on the proliferation of fibroblasts and lymphocytes in vitro, perhaps by inhibiting HMG CO-A reductase, the rate-limiting enzyme in cholesterol biosynthesis, which is consistent with the idea that cholesterol is essential to cell proliferation. Javitt tested this theory by seeding hamster aortic smooth muscle cells at low density in culture wells and coulter counting control and 27-hydroxycholesterol exposed cells six days later. The 27-hydroxycholesterol at the tested concentration inhibited the proliferation by about 50%. Although a potential lead, in vitro muscle cell proliferation inhibition, in itself, does not teach nor suggest the use of the same substance for preventing restenosis in vivo. Indeed, some have interpreted the inhibitory effect by oxysterols on vascular smooth muscle cells as a toxic effect. Zhou, et al., *Proc. Soc. Exp. Biol. Med.*, 202:75-80; Nassem, et al., *Biochem. Internat.*, 14:71-84. Also see Baranowski, et al., *Atherosclerosis*, 41:255-260. Further, it has been recently reported that high doses of Lovastatin, a potent cholesterol lowering drug, in a randomized, double blind placebo controlled trial, did not decrease restenosis six months following percutaneous transluminal coronary angioplasty, although the Lovastatin did markedly decrease LDL-cholesterol level, as expected. Thus, as of today, the cholesterol lowering biological activity of a drug, while perhaps indicating potential use in the treatment of atherosclerosis, is not predicative nor suggestive of use for combating restenosis. As discussed above, restenosis is a multi-faceted phenomena, distinct from atherosclerosis, and the mechanism of which is, at best, only partially understood.

All U.S. patents and publications referred to herein are hereby incorporated by reference.

SUMMARY OF THE INVENTION

Hereinafter, the currently accepted nomenclature for the sterol nucleus involved herein, 27-hydroxy-cholesterol, is employed. It is understood that this compound is identical to the compound named 26-hydroxycholesterol in the prior art discussed above as well as other prior art.

It has now been found that 27-hydroxycholesterol effectively reduces restenosis following injury to the blood vessel lumen which occurs when the lumen is widened by catheter procedure. Therefore, it is an object of the present invention to provide a method for reducing the instance of restenosis which occurs following surgical by-pass procedures and percutaneous angiographic procedures. Further, it is expected that related compounds such as 25-, 26-, and/or 27-aminocholesterol will have a similar effect on the blood vessel lumen.

It is also expected that certain metabolites of 27-hydroxycholesterol, produced by the continuing activity of sterol 27-hydroxylase, are also biologically active. In particular, it is believed that 3 β -hydroxy-5-cholestenoic acid, a metabolite of 27-hydroxycholesterol, may potentiate the activity of 27-hydroxycholesterol by slowing the rate at which the latter is metabolized.

Another object of the present invention is to provide a method for reducing the occurrence of restenosis after balloon, laser or rotameter angioplasty. A further aspect of the present invention involves the administration of a 27-hydroxycholesterol, or related compound immediately following injury to the lumen of a blood vessel as a result of a mechanical widening thereof, and to continue to administer said compound to a patient in a maintenance dosage to prevent restenosis.

In still another embodiment of this invention, the 27-hydroxycholesterol or related compound is administered orally or intravenously, preferably intravenously dissolved in an aqueous solution of a β -cyclodextrin such as 2-hydroxypropyl- β -cyclodextrin.

In another embodiment of the present invention, a sterol 27-hydroxylase stimulant is administered to thereby increase the synthesis of 27-hydroxycholesterol in the vascular tissue. This aspect of the invention is based on a finding of sterol 27-hydroxylase activity in aortic endothelial cells.

In an additional embodiment of the present invention, 27-hydroxycholesterol is administered to a patient in order to inhibit the proliferation of various types of cancer-causing tumor cells.

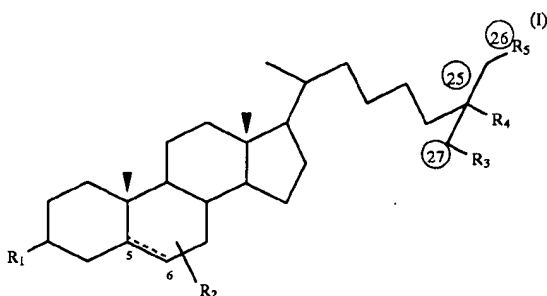
Other objects of the invention will be apparent to the skilled artisan from the detailed description of the invention hereinbelow.

DESCRIPTION OF THE DRAWING

FIG. 1 represents in vitro cytotoxicity test results upon incubation of a 5th uridyl derivative of 27-hydroxycholesterol with HCT-8 cells.

DETAILED DESCRIPTION OF THE INVENTION

The compounds for use in the practice of the present invention are, in general, known in the art, and may be represented by the following formula:



wherein R_1 is hydroxyl or keto; R_2 is hydrogen, hydroxyl or keto; R_3 is hydroxyl, carboxyl, hydrogen or amino; R_4 and R_5 are hydrogen or amino; with the provisos that when R_3 is hydroxyl both R_4 and R_5 are hydrogen, and when R_3 is not hydroxyl, at least one of R_3 , R_4 and R_5 is amino ($-\text{NH}_2$) and the other(s) of them are hydrogen or amino, and pharmaceutically acceptable derivatives and salts thereof. In formula (I), R_3 is substituted at position 27.

A preferred group of compounds for use in the practice of the present invention are those within formula (I) wherein the 27-position (R_3) is substituted by hydroxyl or amino, and each of R_4 and R_5 is hydrogen.

At this time, the most preferred compound for use in the inventive process for reducing and/or preventing restenosis is 27-hydroxycholesterol.

Other compounds usable herein include 25-aminocholesterol, 26-aminocholesterol, 27-aminocholesterol, 27-nor-25-aminocholesterol, 25-aminocholesta-4,6-dien-3-one, 25-aminocholesta-4-en-3-one, 22-aminocholesta-5-en-3 β -ol, 20-amino-25, 26,27-trinorcholesta-5-ene-3 β -ol, 25-aminocholesta-3,5-dien-7-one.

For administration to a patient, the compounds of the present invention can be provided, per se, or as the mono and diesterified derivatives and other pharmaceutically acceptable derivatives thereof such as the mono- and diethers. Most usually, fatty acid, the same or analogous to those naturally occurring, would be used to form the esters, but other inorganic and organic esters, such as acetates, the sulfates, carbonates and glucuronides, routinely employed in preparing pharmaceutically acceptable esters, could be used. Esterification and/or etherification can occur at the 3- and/or 27-position, or at carbon positions 6 or 7 when R_2 is hydroxyl. Aryl and/or alkyl ethers, such as methyl, ethyl or cycloalkyls (i.e., cyclopentyl ethers) are contemplated. Furthermore, acid salts and various substituted compounds, for example, those containing elements such as fluorine commonly used in modification of steroid-type compounds, as long as pharmaceutically acceptable, can be used.

Administration can be through the use of liquid and solid formulations and also through the use of injectables, such as intravenous injectables, wherein conventional pharmaceutical carriers would be employed.

Suitable pharmaceutical preparations include tablets, capsules, oral liquids and parenteral injectables. Tablet and capsule formulations can be employed utilizing conventional diluents, excipients and the like such as lactose in conventional capsule and tablet-making procedures. Parenteral injections could employ solvents conventionally used with lipid-soluble materials, or a salt of the sterol could be prepared, at least some of which should be soluble in aqueous solvents.

It has been difficult to form aqueous solutions of the compounds found herein for parenteral administration. None of the vehicles commonly used to solubilize steroids and bile acids, such as propylene glycol, ethanol, dimethyl sulfoxide or dimethyl formamide, is able to maintain solubility when diluted with aqueous media. As disclosed by DeCaprio, Yen and Javitt, *Journal of Lipid Research*, Vol. 33, pp. 441-443, 1992, 27-hydroxycholesterol, and it is expected the related compounds involved herein, can be stabilized in aqueous media by inclusion of a cyclodextrin therein. It has been theorized that the cyclic structure of the cyclodextrin provides a lipophilic interior in which compounds that have limited aqueous solubility will form a soluble complex. The β -cyclodextrins usable for this purpose are known in the art and are inclusive of the 2-hydroxypropyl- β -cyclodextrin described by DeCaprio, et al., supra. Other non-toxic cyclodextrins would be usable.

The compounds of the present invention are administered in amounts ranging from 10 mg/kg to 100 mg/kg, preferably about 20 mg/kg to 40 mg/kg, 1 to 3 times a day.

In one embodiment of the present invention, the compound of the present invention is administered as a bolus, employing a dosage toward the upper end of the above dosage range, immediately prior to, during and/or following

the blood vessel lumen widening, followed by reduction to a maintenance dosage toward the lower end of the above dosage range. It is contemplated that the maintenance dosage would continue over a prolonged period of time of, for example, 1 to 5 months.

The following non-limiting example is provided to illustrate the above-described aspect of the present invention:

EXAMPLE 1

Vascular Injury Model

New Zealand white rabbits weighing 2.6 to 5.1 kgs were anesthetized with intramuscular ketamine 35 mg/kg. Additional injections of ketamine (100 mg/cc) and xylazine (20 mg/cc) in a 50/50 mixture were given as necessary in 1 ml increments. Keflin (Eli Lilly & Co.), 30/mg/kg was given intravenously (IV). A longitudinal incision was made on the medial aspect of the distal hind limb to expose the greater saphenous artery. Arteriotomy was performed, and a 3-F Fogarty embolectomy catheter (Edwards Laboratories, Santa Ana, Calif.) was introduced and advanced to the level of the diaphragmatic abdominal aorta. The catheter was withdrawn from the abdominal aorta with the balloon inflated to a pressure of about 20 mm hg. This maneuver was repeated for a total of three passes. The catheter was removed, and the saphenous artery was ligated. The wound was irrigated and closed with 4-0 Dexon suture.

Specimen Analysis

The abdominal aortas were fixed by perfusion with glutaraldehyde at physiological pressure via a catheter (14G Intracath) placed in the left ventricle. One micron longitudinal sections of epoxy embedded aorta specimens were cut, stained, and computer imaged. The entire intimal and medial areas in more than 2 sections per specimen were measured using Lucida computer calculation (Micro Brightfield, Inc.). The degree of intimal thickening was determined by calculating the intimal to medial area (I/M) ratio. Statistical significance of the difference in intimal/medial ratio between groups was calculated using student t-test.

Run I

Using the above procedure, a study was carried out employing five control balloon injury rabbits and two groups, each of five balloon injury test rabbits, for receiving 27-hydroxycholesterol or suramin, the latter having been shown to inhibit intimal proliferation.

On the day before surgery, 10 mg 27-hydroxy-cholesterol dissolved in 1.0 ml of 45% aqueous solution of 2-hydroxypropyl- β -cyclodextrin (HPBCD) was administered intravenously to one group of five test rabbits. Suramin was administered to the other test group. bFGF was administered throughout the testing period.

On the day of surgery, a short time prior to the balloon angioplasty, the five test rabbits were administered another 5 mg of 27-hydroxycholesterol in 0.5 ml HPBCD, and the same dosage was administered to each of the five test rabbits twice a day on days 1 to 14 following the day of balloon angioplasty, in the form of 5 mg 27-hydroxycholesterol in 0.5 ml 45% HPBCD twice a day. On day 14, the above specimen analysis was carried out on the fifteen rabbits, with the following results.

QUANTITATIVE HISTOLOGICAL EVALUATION OF ARTERIAL WALL 14 DAYS

	Mean Intima/Media Ratio ¹	
	5-DAY	14-DAY
Control (28 rabbits)	0.094 \pm 0.006	0.5542 \pm 0.024
Suramin Administration		0.4089 \pm 0.034 ²
27-OHcholesterol Administration		0.4872 \pm 0.0238

¹Ratio of thicknesses of intima and media of artery wall

²p < 0.05

This run suggests an improved intima/media ratio through the administration of 27-hydroxycholesterol. However, the results were not as good as with suramin and when calculated, the difference between the control group and the 27-hydroxycholesterol group was not statistically significant. With a suggestion of utility, a further run was carried out with increased 27-hydroxycholesterol dosage.

Run II

Control (vehicle alone) and 27-hydroxycholesterol test rabbits were used as in Run I, with the exception that each test rabbit received 100 mg 27-hydroxy-cholesterol dissolved in 5.0 ml 45% HPBCD subcutaneously on the day before surgery, the day of surgery and on days 1 to 14 following surgery.

QUANTITATIVE HISTOLOGICAL EVALUATION OF ARTERIAL WALL 14 DAYS

	Mean Intima/Media Ratio
Control (28 rabbits)	0.5209 [\pm .001]
Test (20 rabbits)	0.2880 [\pm .024]

The 27-hydroxycholesterol reduced the degree of intimal thickening by nearly $\frac{1}{2}$ as compared with the control group.

In a second aspect of the present invention, a sterol-27-hydroxylase stimulant is administered to increase the sterol-27-hydroxylase activity present in vascular tissue, the presence thereof in vascular tissue being heretofore unknown. In this manner, not only is the available amount of 27-hydroxycholesterol enhanced since it is one of the major metabolites from sterol-27-hydroxylase activity, but the 27-hydroxy-cholesterol is produced in the cells at the location where it is best utilized by the body in reducing and/or preventing restenosis.

The sterol 27-hydroxylase activity in bovine aortic endothelial (BAE) cells in culture has been compared with that in Hep G2 cells and in Chinese hamster ovary (CHO) cells using identical culture conditions. The total enzyme activity of BAE cells (3.0 nmol/72 h/mg cell protein) was comparable with that of Hep G2 cells (4.0 nmol/72 h/mg protein), and both values were significantly greater than that in CHO cells (0.002 nmol/72 h/mg protein). The enzyme was identified in BAE cells by Western blotting using an antibody of proven specificity, and its metabolites 27-hydroxycholesterol and β -hydroxy-5-cholestenic acid were identified by mass spectrum analysis. The presence of the enzyme in endothelium provides a mechanism for providing the biologic effects of 27-hydroxycholesterol in vascular tissue.

EXAMPLE 2

Cell Culture

Bovine aortic endothelial (BAE) cells obtained from a slaughterhouse were plated at low density (2×10^5 cells/cm²)

in 100-mm dishes and were grown to confluence in Dulbecco's modified Eagle medium (DMEM) supplemented with 10% fetal bovine serum (FBS), 50 units/ml penicillin, and 50 units/ml streptomycin at 37° C. in a 5% CO₂ atmosphere. The confluent monolayer was rinsed once with Hank's balanced salt solution, and 4 ml of DMEM containing 10% dialyzed FBS and either 20 μ M cholesterol dissolved in 2-hydroxypropyl- β -cyclodextrin or an equivalent amount of vehicle alone was added to each dish. Hep G2 cells and Chinese hamster ovary cells (CHO) were cultured under identical conditions and for the same length of time. At 24-h intervals, the media and cells were harvested. The medium obtained from each dish was analyzed for metabolites. Cells were pooled for immunoblot analysis.

Western Blotting

Samples were subjected to electrophoresis on a 10% SDS-polyacrylamide gel and were transferred onto a nitrocellulose membrane by an electrophoretic technique. Antibody was raised in rabbits against residues 15 to 28 of the 27-hydroxylase protein. Visualization was accomplished using an alkaline phosphatase-conjugated goat and anti-rabbit antibody followed by the Rad-free kit for calorimetric detection of Western blots (Schleicher & Schuell, Keene, N.H.).

Several attempts were made to detect the 56-kb 27-hydroxylase protein in mitochondria prepared from BAE cells, but despite the use of protease inhibitors, the predominant immunoreactive band was detected at 35 kd, with occasionally a faint band at 56 kd. Boiling freshly harvested whole cells in loading buffer appears to have prevented proteolysis.

GLC-MS Analysis

Sample Preparation

To 1 ml of harvested medium, internal standards (500 ng each) of deuterated 27-hydroxycholesterol, 3 β -hydroxy-5-cholestenic acid (prepared by Jones oxidation of the 3-monoacetate of the deuterated 27-hydroxysterol), and ¹³C-3 β -hydroxy-5-cholestenic acid were added and allowed to equilibrate for 30 min at room temperature. Following acidification and extraction into ethyl acetate, the dried residue was saponified. In some studies, solvolysis was also done prior to extraction. The dried extract was applied to a Silica gel G TLC plate together with authentic standards in parallel lanes; after development (chloroform/acetone, 97:3), the standards were visualized by spraying with phosphomolybdic acid and the appropriate areas of the plate were removed for elution of 27-hydroxy-cholesterol and the C₂₇ and C₂₄ acids. The diacetate of 27-hydroxycholesterol and methyl acetates of the C₂₇ and C₂₄ acids were then prepared using dimethoxy-propane/HCl for methylation and pyridine/acetic anhydride for acetylation. It was found that complete methylation of the C₂₇ acid with dimethoxypropane/HCl took longer than that of the C₂₄ acid. Therefore, methylation was allowed to proceed at room temperature overnight (approximately 18 h). Formation of a 3-methoxy derivative by this prolonged methylation procedure was not detected.

Isotope Ratio Mass Spectrometry

Using a Hewlett-Packard GLC-MS (Model #5890-5970) and a fused silica column (CP-sil 19 CB, 0.25 mm i.d., 25

m length; Chrompack, Raritan, N.J.), the appropriate TLC fractions were injected in the splitless mode with temperature programming from 260° C. to 270° C. at 1.0° C./min and a column head pressure of 5 psi.

To quantify 27-hydroxycholesterol the detector was programmed in the simultaneous ion monitoring mode for m/z 426 [mol ion diacetate=486-60 (acetate)] and m/z 430, and the amount of endogenous 27-hydroxycholesterol was calculated from the respective areas. For the C₂₇ acid, the ion pair that was used was m/z 412 [methyl ester acetate mol ion=476-60 (acetate)] and m/z 416, and for the C₂₄ acid, m/z 370 [mol ion methyl ester acetate=430-60 (acetate)] and m/z 373.

Results

Both the spectra and the retention times of 27-hydroxycholesterol and of 3 β -hydroxy-5-cholestenic acid isolated from the sterol-free medium that was in contact with BAE cells for 72 h are identical to authentic standards of the diacetate and methyl ester diacetate derivatives, respectively.

After the identity of these compounds was established by complete spectrum analysis, an isotope ratio program was used to compare their rates of synthesis in sterol-free and cholesterol-supplemented medium. As shown in Table 1, medium containing 20 nmol/ml of cholesterol yielded a much greater amount of metabolites than sterol-free medium. At 72 h, the metabolites represented approximately 5.8% of the cholesterol added to the medium [(1.029+0.211)-(0.103+0.079) \times 100+20]. Although the amount of 27-hydroxycholesterol in the medium was relatively constant from 24 to 72 h, a progressive increase in the amount of 3 β -hydroxy-5-cholestenic acid occurred. For BAE cells maintained in nonsupplemented medium, the proportion of C₂₇ acid rose from 12% at 24 h to 43% at 72 h. In contrast, although the absolute amount of the C₂₇ bile acid that was synthesized was greater in cholesterol-supplemented medium, it represented only 3.8% of total metabolite at 24 h and increased to 17% at 72 h.

The activity of sterol 27-hydroxylase in BAE cells was compared with that in Hep G2 and CHO cells using the cholesterol-supplemented medium. As shown in Table 2, the amount of 27-hydroxycholesterol in the medium collected from BAE cells at 72 h was greater than that from Hep G2 cells. The amount present in medium from CHO cells was below the limit of detection (10 ng per assay).

The medium from CHO cells always contained a small amount of 3 β -hydroxy-5-cholestenic acid, which was much less than that found in the medium from Hep G2 or BAE cells.

Because Hep G2 cells synthesize 3 β -hydroxy-5-cholestenic acid from 27-hydroxycholesterol, the medium from all the cell lines was analyzed for this derivative before and after solvolysis. No increase in the yield of 3 β -hydroxy-5-cholestenic acid was obtained after solvolysis of media derived from Hep G2 or the other cell lines. Medium from Hep G2 cells was found to contain 3 β -hydroxy-5-cholestenic acid, which increased in amount following solvolysis.

Since all the metabolic products are derived from the sterol 27-hydroxylase activity of the cells, the total amounts produced by Hep G2 and BAE cells are comparable and are much greater than that from CHO cells.

TABLE 1

Synthesis of 27-hydroxycholesterol and 3 β -hydroxy-5-cholestenic acid by BAE Cells: Time course and effect of cholesterol added to the medium.			
Culture Medium	24 h	48 h	72 h
	27-hydroxycholesterol	(pmol/ml)	medium)
Delipidated FBS ^a (n = 4) ^b	89 \pm 12 ^c	98 \pm 11	103 \pm 9
+ 20 nmol/ml cholesterol	1089 \pm 111	1064 \pm 161	1029 \pm 99
	3 β -hydroxy-5-cholestenic acid	(pmol/ml)	medium)
Delipidated FBS	11.9 \pm 1.3	32.0 \pm 1.9	78.6 \pm 11
+ 20 nmol/ml cholesterol	42.5 \pm 6.1	112 \pm 12.4	211 \pm 48.3

^aDelipidated fetal bovine serum^bNumber of dishes^cMean \pm standard deviation

TABLE 2

Comparison of Sterol 27-hydroxylase activity in BAE, Hep G2 and CHO cells				
Cells ^a	Metabolites Derived from Sterol 27-Hydroxylase (pmol/mg/cell protein)			Total
	27OH-chole. ^b	3 β OH-5-cholest. a.	3 β OH-5-chole. a.	
BAE (n = 6) ^c	2555 \pm 348	474 \pm 118	not detected	3029
HEP G2 (n = 6)	1622 \pm 291	471 \pm 126	1940 \pm 270 ^d	4033
CHO (n = 3)	not detected	2 \pm 1	not detected	2

^aAll cells were maintained for 72 h in DMEM enriched with 10% delipidated FBS containing 20 μ M cholesterol.^b27OH-chole = 27-hydroxycholesterol; 3 β OH-cholest. a. = 3 β -hydroxy-5-cholestenic acid;3 β OH-chole. a. = 3 β -hydroxy-5-cholestenic acid.^cNumber of dishes.^dMean value of 2 dishes after solvolysis.

From the above, the positive effects of this invention on restenosis can be provided by stimulating the sterol 27-hydroxylase activity of the vascular endothelium. Various stimulatory mechanisms are known, such as by the administration of steroid hormones, such as the naturally-occurring sex hormones estrogen and testosterone.

The skilled artisan will be able to select other naturally-occurring and synthetic steroid hormones for use in providing a sterol 27-hydroxylase stimulant effect.

An additional experiment was carried out in order to determine the effects of 27-hydroxycholesterol and 3 β -hydroxy-5-cholestenic acid on the proliferation of rabbit, smooth muscle cells. This experiment is presented below:

Effect of 27-Hydroxycholesterol and 3 β -Hydroxy-5-Cholestenic Acid on Rabbit Smooth Muscle Cell Proliferation

Using 96 well microtiter plates, 5000 cells were plated in each well and, after synchronization in Dulbecco's modified Eagle's medium containing 0.1% fetal bovine serum (FBS), the medium was removed and replaced with medium containing 5% dilapidated FBS and the vehicle containing varying concentrations of either 27-hydroxycholesterol or 3 β -hydroxy-5-cholestenic acid. Cell proliferation at 24 hr was measured using formazan formation from MTS which is known to correlate with the number of cells present in each well. At 24 hr, the optical density of wells containing 20 μ M 27-hydroxycholesterol was 0.350 \pm 0.021 and for those containing 3 β -hydroxy-5-cholestenic acid 0.357 \pm 0.22. Compared to control wells (optical density=0.402 \pm 0.037) a significant reduction (p<0.01) occurred indicating that both compounds have an antiproliferation effect directed against rabbit smooth muscle.

Furthermore, an experiment was also performed in order to examine the effect of 27-hydroxycholesterol on the proliferation of cells derived from the rat aorta and the human femoral artery. This experiment is presented below:

Effect of 27-Hydroxycholesterol on Proliferation of Smooth Muscle Cells Derived from Rat Aorta and Human Femoral Artery (Laboratory of Dr. A. Corsini, Institute of Pharmaceutical Sciences, Milan, Italy)

Smooth muscle cells were cultured according to Ross (*J. Cell. Biol.*, 50:172, 1971) from the intima-medial layer of male Sprague-Dawley rats (200–250 g). Cells were grown in monolayers at 37° C. in a humidified atmosphere of 5% CO₂ in MEM supplemented with 10% FBS, 100 U/ml penicillin, 0.1 mg/ml streptomycin, 20 nM tricine buffer and 1% non-essential amino acid solution (Corsini et al, *Atherosclerosis*, 101:117, 1993). The medium was changed every third day. Cells were used between the 4th and 10th passage. Cell viability was assessed by trypan blue exclusion. Smooth muscle cells were identified for growth behavior, morphology, and using monoclonal antibody specific for α -actin, using the isoform typical for smooth muscle cells. Human vascular myocytes were taken from a human femoral artery and grown under the same culture conditions.

Smooth muscle cells derived from rat aorta were seeded at a density of 2 \times 10⁵ and those from the femoral artery at a density of 5 \times 10⁴. After synchronization in MEM containing 0.4% FBS for 48 hr, the medium was replaced with 10% FBS and 27-hydroxycholesterol added. Cell proliferation was determined at 72 hr either by trypsinization of the monolayer and counting in a model ZM Coulter Counter or by incorporation of tritiated thymidine after a 3 hr incubation.

The results are presented in table form below:

27-Hydroxycholesterol Concentration in Medium (μ M)	Growth Smooth Muscle Cells Percent of Control Growth	
	Rat Aorta	Human Femoral A
none (control)	100	100
1.0	90	100
5.0	40*	53*
7.5	18	not done

*p < 0.01

The above-two experiments and data relating thereto provide a mechanism for the reduction that occurs in neointimal hyperplasia following endothelial injury or denudation (i.e., prevention of restenosis). Thus, these additional experiments establish that both 27-hydroxycholesterol and 3 β -hydroxy-5-cholestenoic acid inhibit smooth muscle proliferation and presumably therefore migration of cells into the intima. Smooth muscle cells by both migration and proliferation account for the bulk of the neointima which causes restenosis.

Another embodiment of the present invention relates to the use of 27-hydroxycholesterol in the treatment of different types of cancer, for example, human metastatic colon cancer.

It is well-known that a major cause of death from cancer of the colon is the spread of the cancer cells to the liver. Thus, even after the removal of the primary lesion in the colon, the disease progresses because of continued growth of the tumor cells in the liver with cachexia and death.

Current treatment of metastatic colon cancer includes the infusion of 5-FU (5-fluorouracil) into the portal vein going to the liver.

Because of the inhibitory effect of 27-hydroxycholesterol on a human colon tumor cell line, it is feasible to infuse 27-hydroxycholesterol intravenously into the portal vein or hepatic artery of a patient, although systemic therapy might be just as effective. Additionally, administration via a peripheral vein or subcutaneously or intramuscularly may also be possible. It may, perhaps, also be possible to administer 27-hydroxycholesterol orally as a disuccinate derivative.

In addition to use in the treatment of colon cancer, 27-hydroxycholesterol may also be utilized to treat other metastatic cancers where the metastasis is thought to be confined to the liver. Thus, occasionally, metastatic breast cancer, for example, may also be treated by using 27-hydroxycholesterol. Such therapeutic treatment may be applicable to human use as well as to veterinary use.

The unique value of 27-hydroxycholesterol, in contrast to 5-FU and other chemotherapeutic agents, is the selective effect that can be obtained in only killing the tumor cells.

The rationale for this statement is based on the knowledge that only the normal liver cells have a metabolic pathway for rapidly metabolizing the 27-hydroxycholesterol to normal bile acids which, in the usual concentrations, have no toxic effects. In contrast, tumor cells have no known pathway for metabolizing 27-hydroxycholesterol. Thus, a tumoricidal dose will accumulate only in tumor cells, but the normal liver cells will not be affected.

Moreover, the finding that 27-hydroxycholesterol also inhibits the growth of tumor cells, particularly HCT-8, at a concentration that has been achieved by parenteral administration to rabbits provides further evidence for a new unique chemotherapeutic use for this remarkable compound.

It should also be noted that 27-hydroxycholesterol may be administered with other compounds, such as 3 β -hydroxy-

5-cholestenoic acid, in the treatment of cancer. As noted previously, it is thought that 3 β -hydroxy-5-cholestenoic acid slows down the metabolism of 27-hydroxycholesterol.

An experiment which demonstrated the ability of 27-hydroxycholesterol to inhibit cellular proliferation is presented below:

Effect of 27-Hydroxycholesterol on Cell Proliferation of Tumor Cell Lines (Studies Done in Laboratory of Dr. Joseph Bertino, Program Chairman, Molecular Pharmacology and Therapeutics Sloan-Kettering Institute for Cancer Research, New York, NY)

Tumor Cell Line	Concentration of 27-Hydroxycholesterol Yielding 50% Growth Inhibition
2. L1210 cells (mouse leukemia cell line):	1.2×10^{-6} M
3. K-12 cells (at adenocarcinoma line):	3.7×10^{-6} M
4. HCT-8 (human colon carcinoma)	11.5×10^{-6} M

Conventional methods of cell culture were utilized in this experiment.

As will be noted, the concentrations at which 50% inhibition of cell growth occurs are not extremely potent. However, because 27-hydroxycholesterol is not toxic to normal cells and high concentrations can be achieved by intraportal administration, the range that is indicated as therapeutic in the cell culture studies can be exceeded. (See Table below which indicates the high concentration of 27-hydroxycholesterol found in treated rabbits as well as the plasma concentration of the compound.)

TABLE

Plasma Concentration and Distribution of 27-Hydroxycholesterol			
Control		Treated	
Rabbit #	μ M	Rabbit #	μ M
2016	0.55	342	5.25
345	0.63	343	5.20
384	0.56	385	4.50
386	0.70	387	2.34
388	0.59	390	11.2
Means \pm S.D.	0.61 ± 0.6		5.7 ± 3.3

Distribution of Plasma 27-Hydroxycholesterol					
Nonfasted Rabbits					
Control %			Treated %		
VLDL	LDL	HDL	VLDL	LDL	HDL
3	53	44	34	55	11

27-hydroxycholesterol is not water-soluble. For in vivo use, a good vehicle for administration is hydroxypropyl-beta-cyclodextrin, but the resultant preparation is very viscous and very difficult to infuse intravenously. As a result, another aspect of the present invention is to provide a water-soluble prodrug of 27-hydroxycholesterol for in vivo use. The skilled artisan will be able to prepare various water-soluble derivatives of 27-hydroxycholesterol which, after administration, are acted on within the body of a patient to provide an active 27-hydroxycholesterol moiety. One such example is a 5' nucleoside of 27-hydroxycholesterol,

13

which is water-soluble for ease of injection, such as by intravenous administration.

The following synthesis examples illustrate the preparation of the sodium salt of 3-[(25R)-26-hydroxycholesteryl] 5'-uridyl monophosphate.

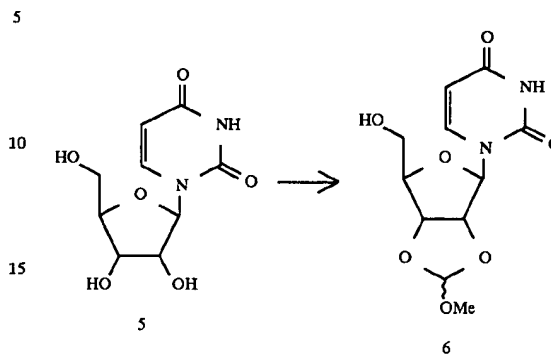
EXAMPLE 3

Synthesis of Sodium Salt of 3-[(25R)-26-hydroxycholesteryl] 5'-uridyl monophosphate

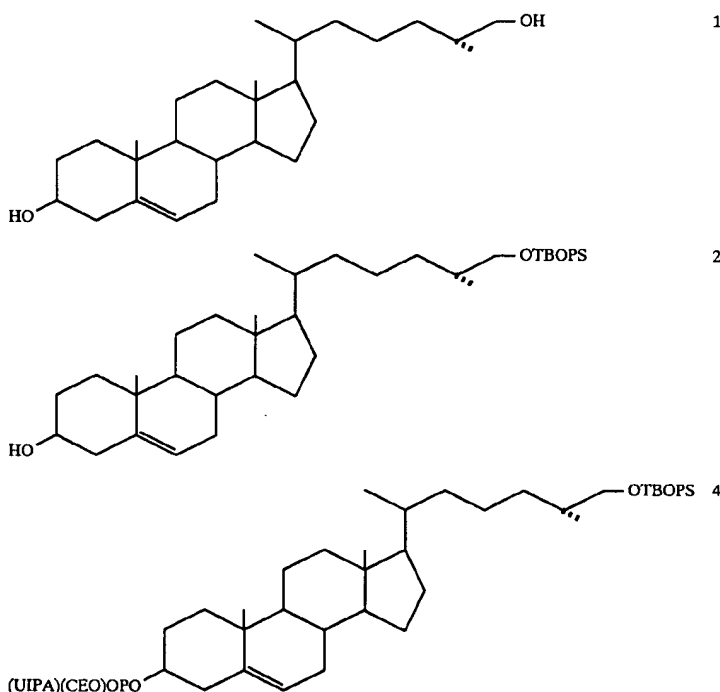
The synthesis of the sodium salt of 3-[(25R)-26-hydroxycholesteryl] 5'-uridyl monophosphate has been accomplished according to the earlier published method. (Y. Ji, W. Bannwarth, B. Luu, *Tetrahedron*, 46:487 (1990)). The final product sodium salt 13 contains oxygenated cholesterol and the nucleoside (uridine) combined by phosphorosexy bonds. The synthesis strategy involved the reaction of phosphine 3 with the 3-OH group of the (25R)-26-hydroxycholesterol 1 followed by the condensation of the product with the primary hydroxyl group of uridine (5). Further oxidation of the phosphorous and removal of the protecting groups leads to the target molecule.

14

between 2 and 3 acetonitrile was evaporated, the residue was dissolved in dry ether and filtered. Evaporation of the solvent yielded compound 4, which was subjected to the next condensation.



The nucleoside part was prepared from uridine 5 after protection of vicinal secondary groups in the form of orthoester. Compound 6 was obtained in this manner and was



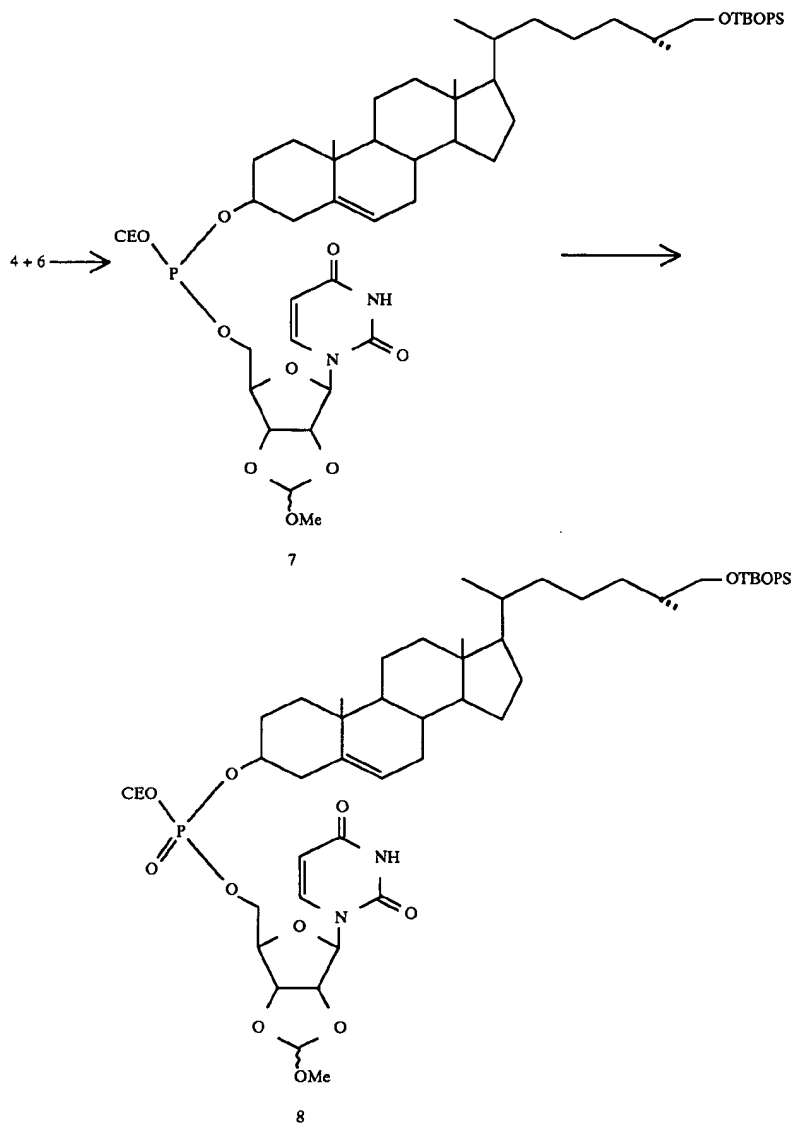
Selective protection of the primary hydroxyl group in compound 1 was achieved by silylation with tertiary butyldiphenylsilyl chloride (hereafter referred to as TBDPSCl) at -20°C . Product 2 was obtained in a 72% yield (in this reaction by TLC another spot was detected with lower polarity which belongs to the 3,26 di(t-butyldiphenylsilyloxy) cholest-5-ene as well as to the silyl impurities from the silylating agent. NMR:N1-1-1.), and when subjected to the reaction with phosphine 3 compound 4 was produced. The authors of the cited publication (*Tetrahedron* 46:487 (1990)) performed fast column chromatography in order to purify. In our hands, flash chromatography did not improve the purity, but instead increased the yield (29%). Moreover we observed decomposition of 4, even on the TLC plates. After the completion of the reaction

reacted with phosphine 4. Generally this reaction yields two products in about equimolar ratio. One is the expected phosphine 7. The other we were not able to identify (NMRN4-3-3).

The above reaction mixture was oxidized in situ. We believe the recommended method of oxidation by MCPBA is not good because epoxidation of the double bond also take place very fast. Instead, we successfully applied such reagents as t-BuOOH, NaIO_4 or simply H_2O_2 . After decomposition of the excess oxidizer and extraction, product 8 was isolated by column chromatography in a 30% yield.

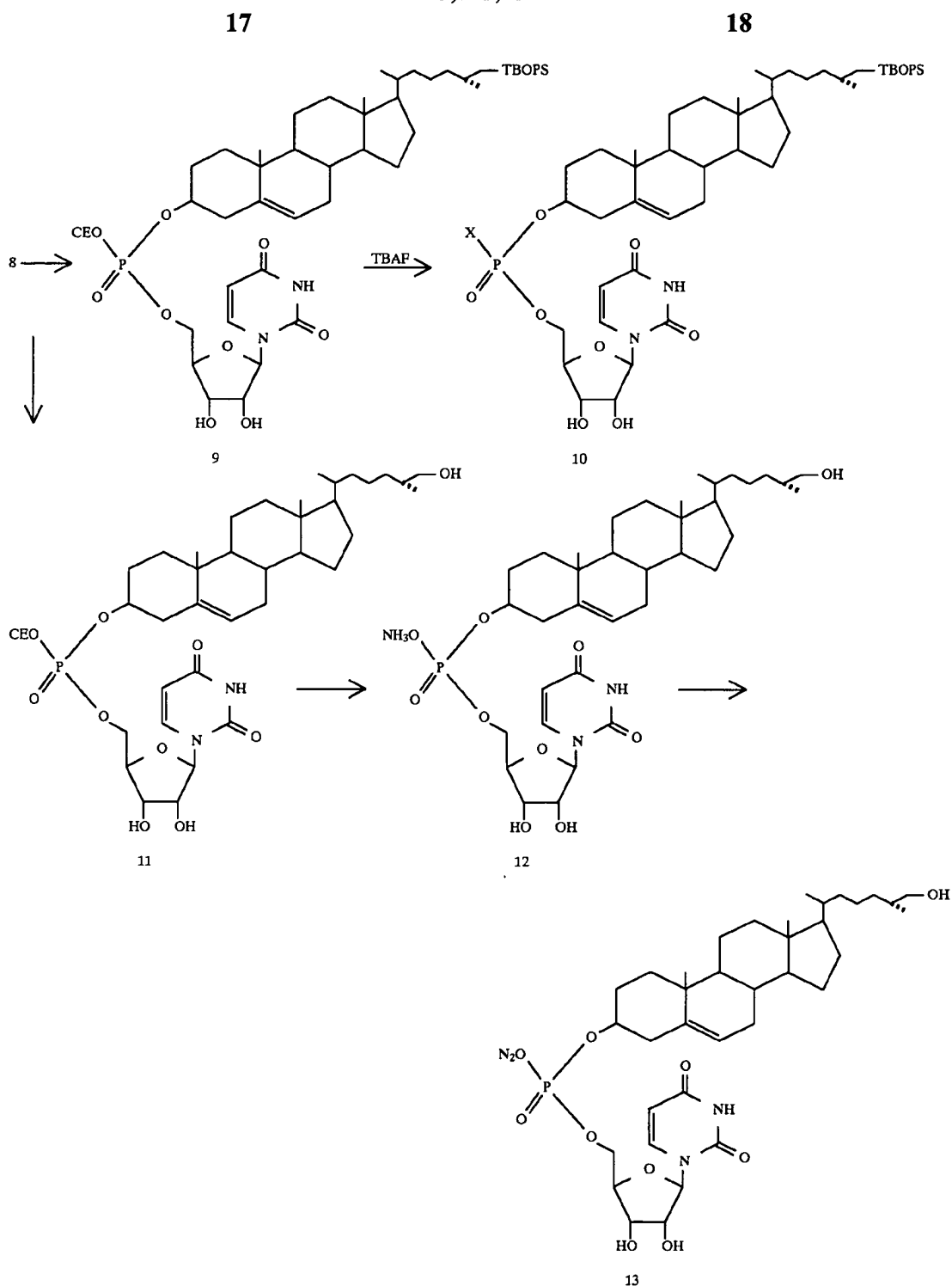
Protection of hydroxyl groups was eliminated in two steps—first by removing of the orthoester moiety and then by desilylation. Protection of the hydroxyl groups in the

nucleoside part was smoothly performed by treatment of 8 with 0.18% HCl in THF. Crude product 9 after extraction was subjected to reaction with 2.5 eq. of TBAF in THF at room temperature. Conversion of 9 was completed in 4 hours, and single product 10 was formed. Unfortunately according to the ^1H NMR (NMR:N5-3-7), it contained the TBDPS part but did not contain the



55

CEO phosphorous protecting group. This probably occurred because of the basic properties of TBAF. Use of HF-py complex (K. C. Nicolau, S. P. Seitz, M. R. Pavia, *J. Am. Chem. Soc.*, 103:1222 (1981)) in wet THF afforded compound 11 as a mixture of two isomers.



60

Removing the β -cyanoethyl group was performed by treatment of the methanolic solution of 11 with concentrated aqueous ammonia. The phosphate ammonium salt 12 thus obtained was converted to the desired sodium salt 13 by ion exchange chromatography on Dowex. Compound 13 gave satisfactory ^1H NMR data.

EXAMPLE 4

Synthesis Example

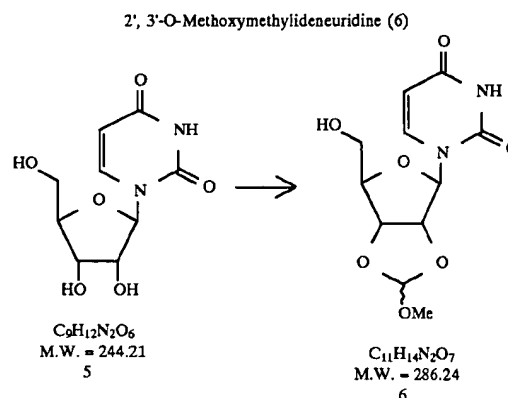
General

Solvents were dried by reflux over a drying agent (CaH_2 for methylene chloride, DMF and MeCN and LiAlH_4 for tetrahydrofuran and diethyl ether) and distilled just before

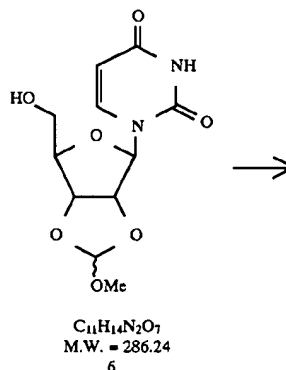
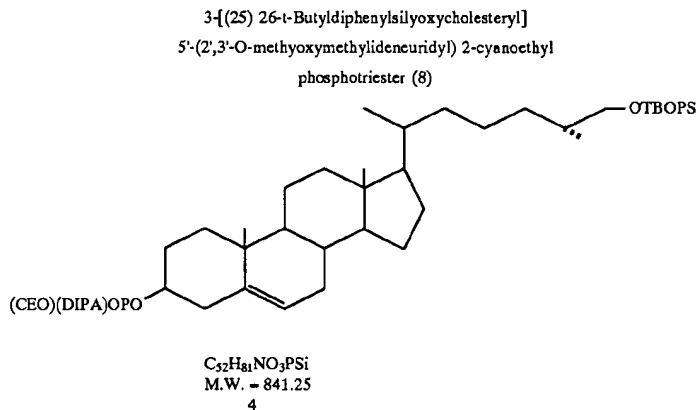
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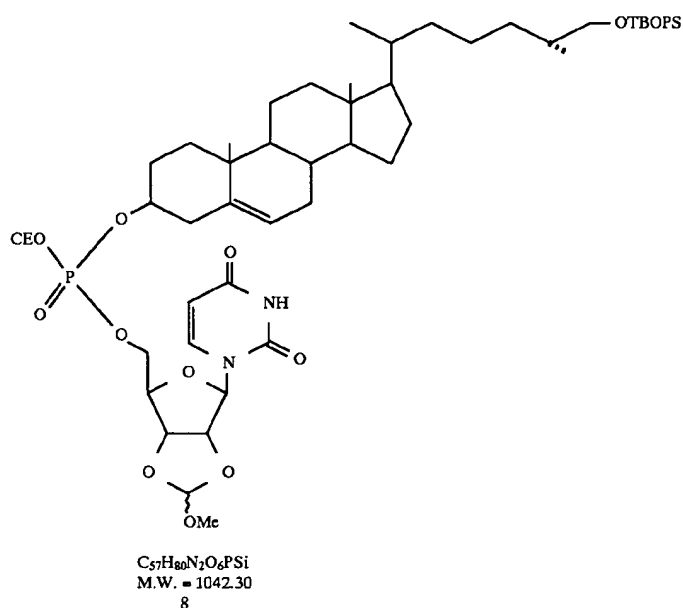
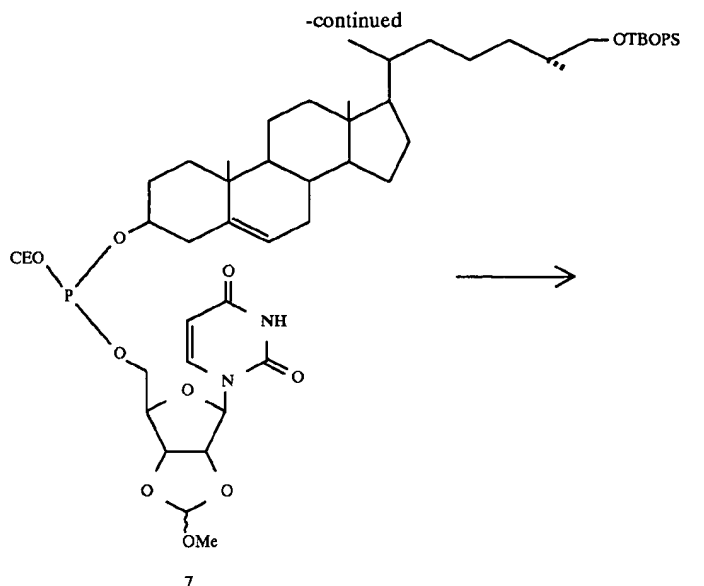
To mixture of 2 stirred under argon at room temperature (0.247 g, 0.39 mmol), diisopropylammonium tetrazolide (73 mg, 0.43 mmol) (obtained after adding diisopropylamine (2.2 ml) to the solution of tetrazole (1 g) in MeCN (7 ml); white precipitate was filtered off and dried under vacuum overnight) and CH_2Cl_2 (10 ml), Phosphine 3 (2-cyanoethoxy bis(diisopropylamino) phosphine (0.128 m, 0.40 mmol) was added. The reaction was monitored by TLC with hexane-ethyl acetate 4:1 as an eluant. (R_F 2 about 0.2, product 4 -0.8). After 2 hours of stirring at room temperature, CH_2Cl_2 was evaporated, the residue was dissolved in ether (30 ml), filtered and evaporated. The resulting phosphine 4 (0.315 g, 97%—colorless oil) was used for the next step without purification.

22



To the suspension of uridine (5) (1.44 g, 5.9 mmol) in trimethyl orthofurmate (20 ml), para toluene sulfonic acid (hereafter referred to as PTOSH) (0.17 g) was added and the reaction mixture was stirred overnight at room temperature. Then the solvent was evaporated under vacuo. The residue was dissolved in a mixture of $\text{MeOH}-\text{CH}_2\text{Cl}_2$ (20 ml), silica gel (2 g) was added and the reaction mixture was left at room temperature. After 3 days, the mixture was filtered and silica gel was washed by the same solvent (4x20 ml). Combined washings and filtrate were evaporated. The product 6 (1.20 g, 71%) was isolated by chromatography. (30 g of silica gel, $\text{CH}_2\text{Cl}_2-\text{MeOH}$ 95:5 eluant.) A white powder mixture of the two diastereomers resulted.





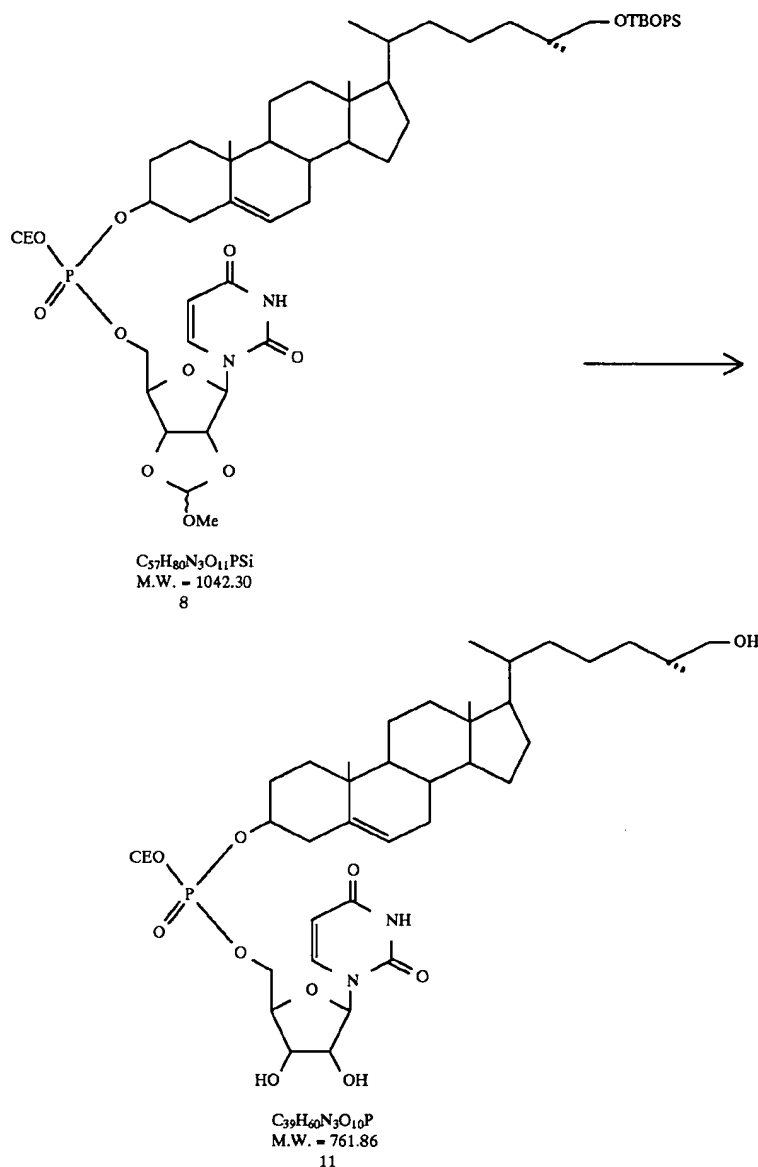
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Phosphine 4 (0.310 g, 0.37 mmol) was taken up in ether (1 ml), cooled to 0° C. and in an argon atmosphere, a solution of nucleoside 6 (0.161 g, 0.56 mmol) in MeCN (15 ml) followed by tetrazole (0.029 g, 0.41 mmol) was added. After a short stirring, the reaction mixture was placed in a refrigerator overnight. The progress of the reaction was monitored by TLC, CHCl₃-acetone 4:1 eluant. After the end of the reaction, two products were visible; R_F=0.75 (side product) and R_F=0.57 (phosphine 7). With vigorous stirring 30%

55

H₂O₂ (0.5 ml) was added. After 5 minutes, excess of oxidizer was decomposed by NaHSO₃ (aq). Water (20 ml) was added and the products were extracted by CHCl₃ (5×10 ml). Combined extracts were dried (MgSO₄) and evaporated. Phosphonate 8 (116 mg, 30%) was isolated from the mixture by column chromatography (15 g of silica gel, CHCl₃-acetone 4:1 eluant). A white powder, mixture of isomers was produced.

3-[(25R)-26-Hydroxycholesteryl]5'-uridyl 2-cyanoethyl phosphotriester (11)



To the cooled to 0° C. solution of 8 (0.230 g, 0.22 mmol) in THF (30 ml) HF-py (1.2 ml) and water (1.4 ml) were added, and the resulting mixture was stirred overnight. The reaction was monitored by TLC, CHCl₃—MeOH 4:1 eluant. In this system two products were observed, R_F=0.8 and 0.75,

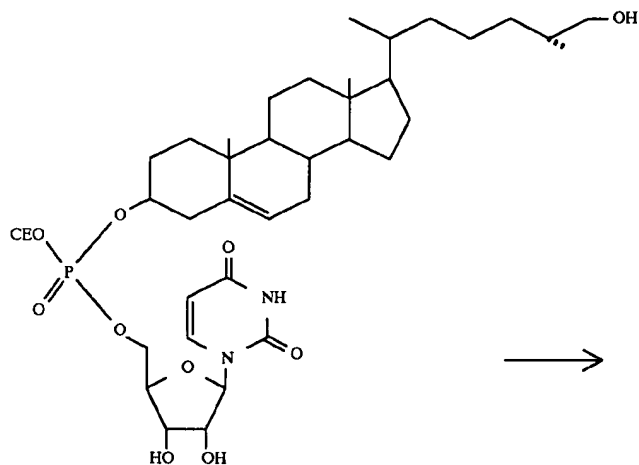
respectively. The products were extracted by CHCl₃ (4×15 ml). Combined extracts were washed by 5% NaHCO₃, dried and evaporated. Products 11 (100 mg, 59%) were isolated by column chromatography (10 g of silica gel, CHCl₃-acetone from 4:1 to 1:1). A white powder was obtained.

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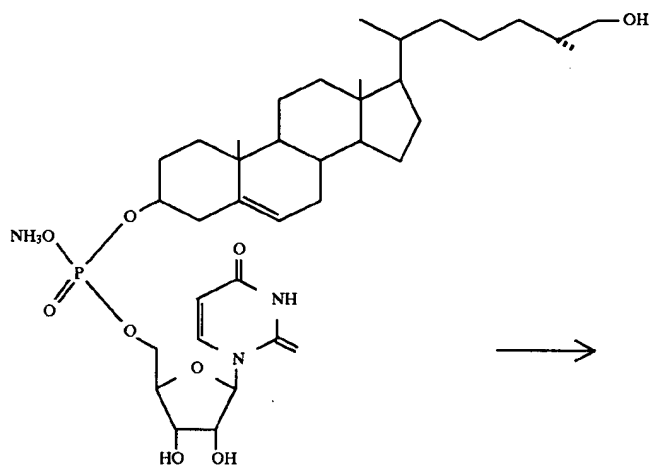
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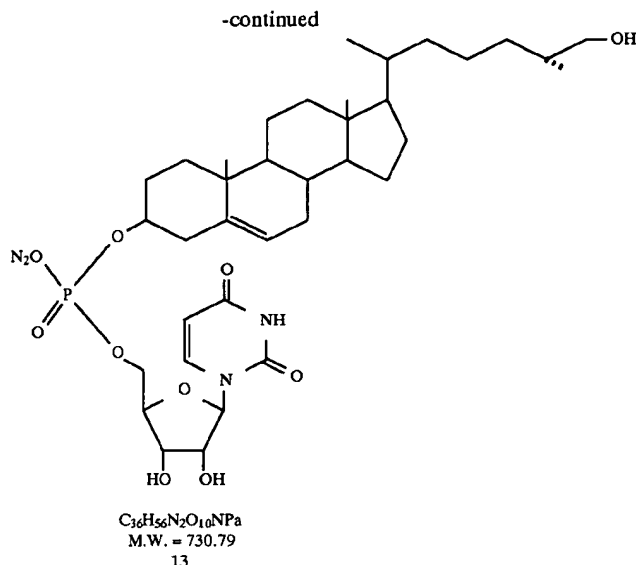
3-[(25R)-26-Hydroxycholesteryl]5'-uridyl
monophosphate, sodium salt (13)



C₃₉H₆₀N₁₀P
M.W. = 761.86
11



12



To the solution of 11 (0.092 g, 12 mmol) in MeOH (10 ml), 25% NH_4OH (10 ml) was added. The mixture was kept at room temperature for 0.5 hour, then solvents were evaporated. The residue was dissolved in deionized water (5 ml) and applied on the column with Dowex resin (20 g). The product was eluted with deionized water. The collected eluate was lyophilized and provided salt 13 (0.082 g, 93%) as a white powder.

EXAMPLE 5

Effect of Sodium Salt of 3-[(25R)-26-hydroxycholesteryl]5'-uridyl monophosphate

Incubation of the HCT-8 cell line with the above-captioned uridine derivative at 500 μM resulted in cell death of the HCT-8 cells. The results of the experimentation is illustrated in FIG. 1.

The results indicate that the percentage of viable cells drops dramatically as the drug concentration increases from 100 to 500 μM after 5 days of exposure. Thus, 3-[(25R)-26-hydroxycholesteryl]5' has potent anticancer properties.

Variations of the invention will be apparent to the skilled artisan.

What is claimed is:

1. A method of treating cancer in a patient comprising administering to a patient, in need of such treatment, an amount of 27-hydroxycholesterol sufficient to effect said treatment in said patient.

2. The method of claim 1, wherein said cancer is a metastatic cancer in which metastasis is confined to the liver.

3. The method of claim 1, wherein said cancer is selected from the group consisting of colon cancer and breast cancer.

4. The method of claim 1, wherein administration of said 27-hydroxycholesterol is selected from the group consisting of intravenous administration, subcutaneous administration, intraperitoneal administration, intramuscular administration and oral administration.

5. The method of claim 4, wherein intravenous administration is via a member selected from the group consisting of the portal vein, the hepatic artery, and a peripheral vein.

6. The method of claim 1, in which a water soluble prodrug of 27-hydroxy cholesterol is administered to the patient.

7. The method of claim 6, in which the water soluble prodrug is a 5'nucleoside of 27-hydroxy cholesterol.

8. The method of claim 7, in which the nucleoside is the 5'uridine derivative of 27-hydroxy cholesterol.

* * * * *